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Vehicle Class-wise Speed Volume model for Three-lane Undivided Urban Roads

Balaji Ponnu[a], Jomy Thomas[a], Kartikeya Jha[b], Gowri Asaithambi[a], Karthik K. Srinivasan[a,*]

[a]*Civil Engineering Department, IIT Madras, Chennai, 600036, India*

[b]*Former Undergraduate Student, BITS Pilani, Rajasthan, 333031, India*

Abstract

Two or three lane two-way undivided roads are a ubiquitous presence in any city in India and they are typically mixed traffic roads with vehicles of widely varying static and dynamic characteristics and with poor or no lane discipline. Hence multi-class speed flow equations are more relevant to these types of facilities rather than single class flow speed models. In addition, the available research for the operation of these types of facilities in India is very limited. Hence this paper aims to study the traffic flow in a three-lane two-way undivided road in the city of Chennai through developing multi-class speed-flow relationships using both linear and Bureau of Public Roads (BPR) models. It has been found from the study that models with total volume perform the same irrespective of units used being vehicles or PCU and models with class-wise (with and without direction) consistently perform better than total volume models. It was also found that linear models work better than other models for all vehicle classes modelling 2-wheeler speeds and two-wheelers, cars and LCVs have the greatest influence on the speeds of almost all the category of vehicles and the stream. One of the other important conclusions from the study is that an optimum use of class-wise and class& direction-wise models can offer models of better fit than two individual class and class-direction models.

Keywords: speed-flow relationship; undivided roads; urban roads; LOS analysis

* Corresponding author. Tel.: +9144-22574282; fax: +9144-22574252
E-mail address: hsmnp@yahoo.com

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1. Introduction

A two or three lane two-way undivided road is a ubiquitous feature in any city in India and in spite of this fact, the research available on operation of these types of facilities is very limited. The research literature available on undivided roads is abundant in developed countries though this is mainly focused on two-lane two-way rural roads which are significantly different from that of urban undivided roads of India. Rural two-lane highways in the developed countries such as the United States are relatively less trafficked and comprise mainly cars and trucks whereas in their urban counterparts in India the traffic varies from free during lean hours to a grid lock during peak periods. In addition, the heterogeneity in vehicle modes and absence of lane discipline make the analysis further complicated in traffic operation from those in developed countries. Hence, it is very clear that the great amount of literature on undivided roads in the developed world can only be used in urban undivided roads in India after accounting appropriately for the heterogeneity in traffic and absence of lane-discipline. Hence this work aims to study the traffic flow on an undivided three-lane two-way urban road in terms of speed-flow relationships. Specifically, more emphasis is given on multi-class speed-versus multi-class flow models as they account for the varying static and dynamic characteristics of different vehicles in a mixed traffic scenario. These multi-class speed flow relationships have extensive applications in traffic engineering as they can be used to calculate speeds for a given traffic volume and composition, perform level of service analysis, estimation of passenger car units &capacity and evaluation of class-based traffic improvement measures. They can also be used in transportation planning studies for evaluating link travel times, for applications involving road user costs and performing traffic assignment.

2.0 Literature Survey

There is a vast amount of literature available on two-lane two-way undivided roads in the developed world, but most of the works study rural roads. Clayton (1941) studied two-lane rural roads in the United States and expressed maximum flow as a function of length of the vehicle and vehicle speed. Greenshields (1961) studied rural undivided roads in United States and expressed flow as a function of average speed, absolute sum of speed changes per unit length of the road and number of speed changes per unit length. Erlander (1967) studied few undivided rural roads in the United States and presented them as curves relating average travel speed and inline and opposing flow rate. HCM (2000) expressed the capacity of two-lane rural road as a function of opposing and total flow rate. In addition it expressed percent time spent following (PTSF) as a function of total flow rate. Luttinen (2001) worked on two-lane rural roads of Finland and expressed space mean speed as a function of free flow speed, inline and opposing flow rates and expressed the coefficients in turn as a function of free-flow speed and road width. This work further expressed speed decrease in a directional traffic as a function of the directional split and space mean speed as a function of total flow rate. Karlaftis and Golias (2002) studied few two-lane roads of Greece and examined the relationships between traffic speeds, flow and traffic stream characteristics. This work used Box-Cox regression and found that average speed is inversely related with ratio of in-lane to opposing lane traffic, car and truck volumes. They also expressed speed in the inside and outside lanes as a function of ratio of in-line to opposing volume traffic. Van As (2007) expressed follower density as an increasing function of total and one-way traffic flow respectively. Karjala (2008) studied a rural two-lane road in Montana, United States and related performance measures such as average travel speed, percent followers and follower density with in-line and opposing volumes, percent no-passing zones, percent heavy vehicles and standard deviation of free-flow speed.

There have been a few studies on two-lane roads in developing countries. Indonesian HCM (1993) uses a function similar to the BPR function to relate speed and total flow of a two-lane undivided road. It also relates average travel speed with the total flow & degree of saturation (V/C), and degree of bunching as a function of degree of saturation. Marwah and Singh (2000) carried out a study on city roads of Kanpur through a validated simulation model. For a known vehicular composition, they expressed mean journey speed as a function of flow rate. Bang and Henshen (2000) conducted study on Chinese inter-urban roads and expressed speed as a function of degree of saturation for a known vehicle composition. Chandra and Kumar (2003) related mean stream speed with the volume for two-lane rural highways in India under mixed traffic conditions. This work also expressed capacity as a function of percent traffic in main direction and found that capacity decreases as the proportion of traffic in the in-line direction increases. Rahman and Nakamura (2005) studied the passing overtaking characteristics, LOS and the effect of non-motorized vehicles on these parameters on undivided urban roads in Bangladesh with high proportion of NMT. Rong, Guo and Zhou (2011) studied few Chinese highways wherein they expressed average travel speed as a function of total flow rate, overtaking ratio and acceleration noise. . Sharma et *al.* (2011) studied two-lane rural roads in Rajasthan, India and developed all three macroscopic relationships.

Additional review of literature on speed-flow relationships for Indian roads revealed that though there are many papers that focus on single class speed-flow relationships such that of Chandra and Sikdar (2000), Arasan and Krishnamurthy (2007),Sharma *et al.* (2011), there are two works that investigate multi-class speed flow relationships viz. Thomas et al. (2011 and 2012) and develop performance measures for a four and six-lane urban roads respectively using simulated data. This work is strongly influenced by these two works and attempts to do the same but with two stark differences; it uses field data instead of simulation and it focuses on undivided roads whereas the former dwelled upon divided roads.

In sum, the above literature review gives us many useful insights about undivided roads in general. In developed countries such as the United States or Finland, few authors have expressed speed as an inverse function of total flows while some others have taken flows in same direction (in-line flow) and flows in opposing direction(opposing flow) separately.

Studies on undivided roads in developing countries have dealt with similar type of speed-flow relationships, but restricting them to single class speed-flow models not accounting for the heterogeneity in vehicle classes. It is also clear that there are very few papers available on the operation of two-lane two-way undivided urban roads in India with an emphasis on multi-class speed-flow relationships that account for heterogeneity of traffic. In homogeneous or mixed traffic conditions, the opposing traffic will certainly have a different effect than that of the traffic in the same direction on a three lane undivided road, given a chance of head-on collision. Further research is envisaged to ascertain which is more pertinent, total volume or direction-wise volumes on class-wise speeds on an undivided road. Hence this work aims to study the same for a three-lane two-way undivided urban road in the city of Chennai, India through field study.

3.0 Data Collection

To develop the speed-flow relationships, traffic data was obtained by videography between Check post and Halda Junction on Velachery Main Road in the city of Chennai on the 5rd and 6th of June, 2012 during morning(8:00 to 12:00hours) and evening peak(16:00 to 18:00) hours. The test section was of a length of 458.8m and hence, two cameras were used to collect the data one at the entrance and one at the exit of the test section. The travel times of 10% of vehicles on this stretch were estimated using vehicle re-identification technique for each successive five minute interval. The class-wise volumes of vehicles on each of the direction were also extracted from the video. Then the average speeds for a given 5-minute interval of each class of vehicle and the stream were calculated from the stretch length and the travel time samples. These average speeds are then matched with the 5 minute class and direction-wise volume counts on a given day and hour and this forms the basis for the speed-flow analysis.

4.0 Model Specification

Two well-known formulations for speed flows viz. linear regression and Bureau of Public Roads (BPR) models were chosen to be tested out for best fit. Since there are two classes of models involved viz. linear and BPR (non-linear), comparing R^2 (which is essentially a parameter that is more readily applicable for linear models) would not be correct. This is reason for MAPE being considered as a MOE (measure of effectiveness) in this paper, which can be applied commonly for both types of models. Nevertheless, R^2 can be calculated for both linear and non-linear models and is furnished in Table 1.

As regards flows, three possible combinations were tried namely total flows, class-wise total flows and class and direction-wise flows. Non-motorized vehicles are not considered in this paper due to difficulty in data collection and only very less amount of non-motorized vehicles are present in the road section. The general formulation of the three models used in the analysis with linear regression is as follows:

a) Class-wise Speed Total Flow Models
$V_i = a_0 + a_1 * q_t$
b) Class-wise Speed Class-wise Flow Models
$V_i = b_0 + b_1 * fi + b_2 * q_2 + b_3 * q_3 + b_4 * q_4 + b_5 * q_5$
c) Class-wise Speed Class and Direction-wise Flow Models
$V_i = c_0 + c_{11} * q_{11} + c_{21} * q_{21} + c_{31} * q_{31} + c_{41} * q_{41} + c_{51} * q_{51} + c_{12} * q_{12} + c_{22} * q_{22} + c_{32} * q_{32} + c_{42} * q_{42} + c_{52} * q_{52}$
d) A mix of models b) and c) if found more relevant

Where V_i refers to speed of vehicle class i and qt is the total volume, q_1, q_2, q_3, q_4 and q_5 represents the class-wise volumes of auto, two-wheeler, bus, car and light commercial vehicle on the entire road width respectively in model b. q_{11}, q_{21}, ...q_{51} represent the in-line volumes of auto, two-wheeler, bus, car and LCV respectively and q_{12}, q_{22}, ...q_{52} represent the opposing volumes of auto, two-wheeler, bus, car and LCV respectively, in model c, while a, b and c represent the respective coefficients for each term. All volumes are in the units of veh/hr whereas all speeds are in km/hr.

The general formulation for the three types of BPR models used in the analysis is as follows:

a) Class-wise Speed Total Flow Models
$V_i = V_{FFS} / [1+\alpha(q_t)^{\beta}]$
b) Class-wise Speed Class-wise Flow Models
$V_i = V_{FFS} / [1+\alpha_1(q_1)^{\beta}{}_1 + \alpha_2(q_2)^{\beta}{}_2 + \alpha 3(q_3)^{\beta}{}_3 + \alpha_4(q_4)^{\beta 4} + \alpha_5(q_5)^{\beta}{}_5]$

c) Class-wise Speed Class and Direction-wise Flow Models
$V_i = V_{FFS} / [1+\alpha_1(q_{11})^{\beta}{}_1 + \alpha_2(q_{21})^{\beta}{}_2 + \alpha 3(q_{31})^{\beta}{}_3 + \alpha_4(q_{41})^{\beta 4} + \alpha_5(q_{51})^{\beta}{}_5 + \alpha_6(q_{12})^{\beta}{}_6] + \alpha_7(q_{22})^{\beta}{}_7 + \alpha_8(q_{32})^{\beta}{}_8 + \alpha_9(q_{42})^{\beta}{}_9 + \alpha_{10}(q_{52})^{\beta}{}_{10}]$
d) A mix of models b) and c) if found more relevant

Here all q's represent volumes as in linear model specification above while α and β represent the BPR model parameters.

5.0 Analysis and Discussion of Results

The collected data was analysed and different classes of models, viz. total volume, class-wise volumes and class and direction-wise volumes and a mix of class and direction-wise models (b and c as explained above) were fit to the data. It was found from the analysis that linear models performed better than BPR models for all vehicle classes. Except for two vehicle classes' viz. auto and bus, models of type d performed the best for the three remaining vehicle classes and also the stream. The best performing models are summarized in Table 1 which also informs us about the influence of different class volumes on the speed of a given vehicle class. It can be observed from the table that the speed of auto is influenced the highest by LCVs in the same direction followed by 2-wheeler and cars coming from the opposite direction. The speed of bus is affected the maximum by the LCVs in the same direction followed by the 2-wheelers in the opposite direction. The speed of 2-wheelers is influenced to the highest by the total volume of LCV on the road. This may be attributed to the fact that LCVs tend to stay in their own lane given their bigger size and lesser manoeuvring capabilities and they affect the two-wheelers irrespective of if they are in the same lane or in the opposite. The speed of cars is influenced the most by two-wheelers in the opposite direction and total volume of cars (combining both directions). It was interesting to note that both LCV and the entire traffic stream was affected the most by two-wheelers in the opposite direction and cars in the same direction. It can be further added that for most of the vehicle classes, two-wheelers coming from the opposite direction had a strong if not highest influence which the authors believe is due to the high manoeuvrability of the two-wheelers. Two-wheelers can also tend to take the opposite lanes more frequently than other vehicle modes owing to their small size and capability to return to their own lane in a moment once a bigger vehicle is encountered in the front. It can also be noted that cars in the opposing direction also had a strong influence on auto and bus and this also can be linked to the high manoeuvrability of car and their high acceleration capabilities.

Table 1. Summary of Multi-class Speed Flow Models

Eqn No	Vehicle Class	Best Performing Model
1	Auto	V_{au} = 45.398-0.003q_{41}-0.011q_{51}-0.005q_{22}-0.005q_{42}(R2 = 0.423, n =72 , MAPE = 5.00)
2	2-whe -eler	V_{2w} = 56.182-0.010q_{22} - .001q_1 – 0.003 q_4- 0.015q_5 (R2=0.398. n = 73, MAPE = 7.23)
3	Bus	V_{bus} = 45.244 - 0.001 q_{21} - 0.004 q_{23} - 0.026q_{51} -0.008q_{12}-0.003q_{22}-0.005q_{42} (R2=0.211 , n=55, MAPE =7.45)
4	Car	V_{car} = 49.764-0.004q_4-0.007q_{22} - 0.003 q_1 (R2= 0.467, n = 72, , MAPE =5.39)
5	LCV	V_{LCV} = 46.762-0.005q_{41}-0.006q_{22}-0.002q_1-.004q_5 (R2= 0.388, n = 70, , MAPE =6.53)
6	Stream	V_{stm} = 45.446 - 0.004 q_{41} - 0.007 q_{22} - 0.003 q_1 (R2= 0.460, n= 72, , MAPE =6.02)

Here n refers to the number of samples used for different models

The speed flow relationships also helped us in knowing if models with class-wise speeds as a function of total volumes in PCU would be better or if total volumes in vehicles would offer a better fit. As shown in Table 2 linear model for each vehicle class with total volumes in either PCU or vehicles does not differ in MAPE significantly (by more than 5%). Similar results were observed for BPR models also and the difference in MAPE between two models for each vehicle class is not more than 6%. The difference in MAPE here refers to the difference between PCU and vehicles based volume models. For example, in case of auto the MAPE for PCU model is 5.915% and the same for vehicle based model is 5.889%, the difference between these two MAPEs is lesser than 5%, which is also the case for other vehicle classes.

Table 2. Comparative Performance of Linear Type a) models in PCU and vehicles

model	class	units	nobs	a_0	a_1	MAPE	SSE
linear regression	auto	PCU	72	41.885	-0.002	5.915%	521.471
		Veh	72	40.695	-0.001	5.889%	516.974
	2-W	PCU	73	50.178	-0.003	8.720%	1727.005
		Veh	73	48.129	-0.002	8.681%	1736.661
	bus	PCU	55	42.306	-0.002	7.949%	806.119
		veh	55	41.197	-0.001	8.062%	803.041
	car	PCU	72	46.522	-0.002	7.122%	886.380
		Veh	72	44.906	-0.002	6.810%	880.710
	LCV	PCU	70	44.706	-0.002	7.787%	887.413
		Veh	70	43.275	-0.002	7.975%	874.393
	stream	PCU	73	47.960	-0.002	7.084%	1042.511
		veh	73	46.051	-0.002	7.151%	1049.424

As an additional scope, this study aimed at comparing if class-wise speed models with total volume in PCU performed well in terms of MAPE than class-wise and class and direction wise volume models for both linear and BPR types of models. As shown in the Table 3, in case of linear models the performance in terms of class-wise MAPE consistently decreases from total volume models, class-wise volumes and class and direction wise models in that order for all vehicle classes and stream except for 2-wheeler, when there is a sudden jump in model MAPE of type c models to 23%. The same was observed in case of BPR models for all vehicle classes except for stream speed when the model MAPE of type c models shoots up to 7.3%. The improvement in model performance can also be visualized as the decrease in the sum of squared errors of each model as displayed in Table 3. The PCU and vehicle units side by side is to check if there is any change in performance of the models when considering them. Also, had there been great difference between the two and one among them performed better, we would have also known which one is more suitable to be used in modelling undivided roads.

Table 3 Comparative Performance of Total and Class-wise Volume Linear Models

model	class	model	units	MAPE	SSE
Linear Regression	auto	a	PCU	5.92%	521.471
		b	Veh	5.52%	475.636
		c	Veh	5.00%	398.950
	2-wheeler	a	PCU	8.72%	1727.005
		b	Veh	8.50%	1643.654
		c	Veh	23.52%	1232.900
	bus	a	PCU	7.95%	806.119
		b	Veh	7.77%	791.090
		c	Veh	7.45%	718.239
	car	a	PCU	7.12%	886.380
		b	Veh	6.85%	796.634
		c	Veh	5.64%	616.036
	LCV	a	PCU	7.79%	887.413
		b	Veh	7.24%	798.974
		c	Veh	6.66%	691.670
	stream	a	PCU	7.08%	1042.511
		b	veh	6.93%	952.368
		c	veh	6.09%	716.403

Conclusions

The following conclusions can be drawn from this study

1. For undivided roads in this study, linear models performed better in terms of MAPE for all vehicle classes such as auto, car, LCV, bus and stream. Also, among the linear models, a combination of class-wise and class& direction-wise models performed the best for four (except for auto and bus) out of six vehicle classes. Hence an optimum use of the combination of multi-class volume models and multi-class and direction-wise models can yield models that can offer best performance in terms of fit.
2. It has been found from the study that 2-wheelers and cars in the opposite direction strongly influence the speeds of almost all of the classes. This is because of their maneuverability& acceleration capabilities and a tendency to drive on the opposite lanes as they can always move again to their own lane within a very small fraction of time. LCVs in the same direction or in total, also influence speeds of auto, 2-wheeler, bus and LCVs(themselves) due to their relatively low speeds (w.r.t other classes in the stream) and they many a times function as moving bottlenecks.
3. Both multi-class speed flow models with class-wise volumes perform consistently better than multi-class speed flow models with total volume in PCU, and this was observed for all vehicle classes. Internally between the multi-class volume models, direction-wise models lead to a lesser MAPE and hence perform better.

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